MUNICIPAL SOLID WASTE CHARACTERIZATION AND ANALYSIS IN TRICITY

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By

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ABSTRACT

Unscientific disposal of waste has been found to be related with numerous environmental concerns like air, water and soil pollution. This requires immediate attention to minimize impact of solid waste on environment and health. Generation of waste is directly influenced by economic development. Most of the municipal authorities in developing countries are facing challenge to manage it in an effective and efficient manner. Solid waste generation and its composition are influenced by a number of factors like geographic condition, season, life style, eating habits, population growth and social status. Therefore, it has become important to take into consideration all these factor and ascertain composition and quantity of waste before selecting and implementing waste management strategies for a particular area. Waste treatment option suitable for a particular area may not be necessarily effective for another area. Therefore, selection of treatment options for particular locality should be made keeping in view various factors like waste generation trends, variation in waste composition and population growth rate.

Considering the current environmental as well as public health issues the present study aims to investigate the current waste management practices in Tricity of Chandigarh, Mohali and Panchkula and to know the environmental repercussions due to the generation of leachate from the open dumping sites and to explore the life cycle assessment methodology to determine the impact of municipal solid waste management under different scenarios. The evaluation of the waste management in Tricity was determined using the 'wasteaware' benchmark indicators and remedial measures suggested. The wasteaware benchmark indicators for Mohali and Panchkula show very poor performance in environmentally controlled waste treatment, disposal method of waste and the *3R* methodology in comparison to Chandigarh.

The success of the integrated solid waste management system depends upon the amount and type generated from different sources for better facilitating of the appropriate management system. In this context, the present study characterizes the physical and chemical properties of the Municipal Solid Waste (MSW) generated in all the three study locations for different socio-economic groups. The characterization of the three cities indicates that MSW generated from all the three cities have high proportions of biodegradables [52% Chandigarh (CHD), 46.7% Mohali (MOH) and 42.6% Panchkula (PKL)] with inert fraction as (27% in CHD, 28.6% in MOH and 28.46% in PKL). Chemical characterization results of MSW reveal

variation in elemental carbon with carbon fraction reported being 34.18% in CHD, 33.8% in MOH and 31.9% in PKL city. In the context of the characterization study, the suitable alternatives to the existing MSW management practices including composting, vermicomposting, setting up of a formal recycling unit and installation of bio-methanation plant along with the existing refuse derived fuel (RDF) plant as a comprehensive process for handling the municipal solid waste generated in the Tricity region.

The study also assesses the impact of the landfill pollution on the ground water quality of the three unlined landfill sites of Chandigarh, Mohali and Panchkula. Leachate and ground water samples were analyzed for various physico-chemical, biological and heavy metals. Contamination of ground water samples in all the three cities of Chandigarh, Mohali and Panchkula is owed to the percolation due to leachate. The effect of leachate samples on viability of Neuro-2a cell line was evaluated using MTT assay. The overall results of MTT assay suggest that the landfill leachate from three sites significantly contained cytotoxic compounds. The concentration of carcinogenic PAHs as specified by BaP TEQ's was found in the range from 32.4972 $\times 10^{-2}$ to 78.2571$\times 10^{-2}$ mg/lt. The cancer risk (CR) varied from 2.90$\times 10^{-4}$ to 7.00$\times 10^{-4}$. The cancer risk measured due to PAHs did not exceed the risk threshold under the present conditions however with the increased generation of MSW and no proper control measures in place the cancer risk potential may increase in the very near future. Further, the toxic effects due to other organics as well as inorganic contaminants as specified in the results of the current study cannot be neglected.

The study assesses the pollution potential of leachate generated from three non-engineered landfill sites located in the Tricity region LPI signifies the level of pollution concentration of a landfill. The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water. WQI is calculated using OWQI method and values for all the three cities of Chandigarh, Mohali and Panchkula respectively. The values of WQI obtained were Chandigarh 83.8, 73.5 and 72.4, Mohali 54.3, 58.3 and 66.1, Panchkula 80.8, 77 and 71.4 during first, second and third sampling respectively. The outcome of quality of ground water for Chandigarh lies from "fair quality of water" to "poor quality of water", for Mohali and Panchkula; it is ranged as "very poor quality" to "poor quality of ground water". Multivariate Analysis in the form of Principal component analysis (PCA) and Hierarchal Cluster analysis (HCA) was also performed. Principal component analysis (PCA) carried out established

major components mainly from natural and anthropogenic sources with cumulative variance of 88% for Chandigarh, 87.1% for Mohali and 87.8% for Panchkula. Hierarchical cluster analysis (HCA) identifies three distinct cluster types for the groundwater samples. These clusters corresponds to a relatively low pollution, moderate pollution and high pollution regions.

Life cycle assessment (LCA) is a tool to quantify environmental burdens associated with products or activities throughout their life cycle. The study analyses the impacts of different potential waste management alternatives for Tricity using LCA approach. Five potential scenarios of scientific solid waste management were analysed. The impact categories analysed were global warming, acidification, eutrophication and human toxicity. In the study, the LCA was accomplished using the Simapro software version 8.3.0 and expressed with the Eco-Indicator 99 (H) and Eco-Invent method. The sensitivity analysis identifies sensitive parameters, that is, whether a small change in input parameter would induce a large change in impact category. The input parameters for sensitivity analysis focus on the recycling rate. Among the proposed alternative scenarios, the scenario with the combination of recycling, composting and sanitary landfill has least environmental impacts. The results show that the significant environmental savings are achieved through the energy recovery in all the integrated waste management scenarios. It is clear that there is no single MSW management scenario that performs best in all the impact categories.

Keywords: Municipal Solid Waste Management, Wasteaware Benchmark Parameters, Landfill Leachate, Neuro-2a Cell Lines, LCA

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1. INTRODUCTION

1.1. Solid Waste

Solid waste comprises of different materials like papers, glasses, wood, plastics, vegetable wastes, food wastes, construction and demolition (C&D) wastes, radioactive wastes and hazardous wastes. Solid wastes are the wastes arising from the human and animal activities that are useless remains from places of human and animal habitation. The term 'Municipal Solid Waste (MSW)' is generally referred to as the discarded material generated by the daily activities from residential, commercial, institutional and other areas excluding the bio-medical and hazardous wastes. The unscientific management and disposal of waste leads to serious environmental problems. These problems are already acute in cities and towns as the disposal facilities or areas do not keep pace with the quantum of waste being generated. Solid waste generation has reached an alarming proportion in the globalized world due to industrialization and rise in population. Therefore, it is essential to comprehend the sources, composition, and amount of waste generated, collection, transportation and disposal practices for planning effective solid waste management strategy for a specific area.

1.2 Status of Solid Waste Management in India

Solid Waste Management (SWM) refers to a combination of various elements like generation, collection, transportation and disposal to certify minimal environmental effects. In India, the management of solid waste is looked after by the municipal authorities of the respective states or cities. Since the past few decades, India has witnessed higher urban population due to migration of people which puts pressure on resources and leads to generation of solid waste in higher amount (Mor et al, 2006; Das et al, 2014; De et al, 2016). With the launch of the flagship programme by the Government of India, Swachh Bharat Mission in 2014 under which aims to provide basic infrastructural services with respect to sanitation facilities including toilets and adopting the scientific methods to collect, process and disposal of MSW (Hazra et al, 2009; Greene et al. 2014).

As per Central Pollution Control Board (CPCB, 2016) only 31% of Indian population resides in urban areas and this population generates gigantic 1, 43,449 metric tonnes per day of

MSW and yet urban solid waste management in India continues to remain one of the most neglected areas due to lack of awareness at all levels, poor implementation of laws and financial constraints (Manikandan et al, 2014; Kaur et al, 2015). The per capita waste generation rate in major cities ranges from 0.20 -0.6 Kg (Chidanand et al, 2013). Table 1.2 shows the state wise MSW generation in Indian cities. The collection efficiency in major cities generally ranges between 70-90% whereas for smaller cities it is even below 50%. MSW collection and disposal is one of the major problems to be dealt with at present.

Table 1.2: Municipal Solid Waste Generation in India (State-wise); source CPCB, 2015

S.No	Name of the State/UT	Municipal Solid Waste MT/Day (2009-2012)	S.No	Name of the State/UT	Municipal Solid Waste MT/Day (2009-2012)
1.	Andaman & Nicobar	50	18.	Lakshadweep	21
2.	Andhra Pradesh	11500	19.	Maharashtra	19.204
3.	Arunachal Pradesh	93.802	20.	Manipur	112.9
4.	Assam	1146.28	21.	Meghalaya	284.6
5.	Bihar	1670	22.	Mizoram	4742
6.	Chandigarh	380	23.	Madhya Pradesh	4500
7.	Chhattisgarh	1167	24.	Nagaland	187.6
8.	Daman Diu & Dadra	41	25.	Orissa	2239.2
9.	Delhi	7384	26.	Puducherry	380
10.	Goa	193	27.	Punjab	2793.5
11.	Gujarat	7378.775	28.	Rajasthan	5037.3
12.	Haryana	536.85	29.	Sikkim	40
13.	Himachal Pradesh	304.3	30.	Tamil Nadu	12504
14.	Jammu & Kashmir	1792	31.	Tripura	360
15.	Jharkhand	1710	32.	Uttar Pradesh	11.585
16.	Karnataka	6500	33.	Uttaranchal	752
17.	Kerala	8338	34.	West Bengal	12557
Total					**127485.107**

Municipal agencies spend about 5-25% of their budget on MSW management. Urban Local Bodies (ULB) spends approximately Rs.500 to Rs.1500 per ton on MSW for collection, transportation, treatment and disposal. About 60-70% is spent on street sweeping of waste collection, 20-30% on transportation and a less than 5% on disposal. Landfill sites are not being properly identified by the municipalities. For long term planning of economic solution a formation of a system for a long term sustainable basis is very essential.

1.3 Environmental Impacts

In India major portion of the MSW is discarded in open dumping sites without giving any prior treatment. Dumping of MSW in open sites will have significant impact on the environment and also effect health of humans and other living beings in the vicinity area (Gajski et al, 2012; Faccio et al 2011). Major fraction of the MSW includes organic components therefore soon after dumping waste will undergo changes which lead to generation of various emissions in the form of leachate and gases. The biodegradable fragment present in MSW undertakes various biogeochemical and hydrological reactions in the presence of moisture to produce a liquid generally termed as 'leachate'. Many studies (Thakur et al, 2015; Talalaj et al, 2016; Yadav et al, 2014; Ghosh et al, 2014a; 2014b) reported that leachate contains numerous organic and inorganic compounds like humic acids, salts, ammonical nitrogen and heavy metals. Anaerobic degradation of MSW leads to generation of gases like methane (CH_4) and carbon dioxide (CO_2). Landfill gases are directly emitted to the atmosphere from the open dump sites and are considered to be major contributor of global warming due to emission of methane a greenhouse gas (GHG) which has 21 times more global warming potential as compared to carbon dioxide. A number of studies (Kaur et al, 2016; Giusti, 2009; Guerrero et al, 2015; Gupta and Rajamani, 2015; Rana et al., 2014; 2016) have also reported that a higher percentage of workers involved in handling of refuse or the individuals living near the dumping sites are suffering from various types of health problems like gastrointestinal parasites, worms and other related organisms.

1.4 Waste Management Policies in India

Various rules and policies have been framed in India to tackle the problems of waste with an aim to reduce the risks to human health and environment. MSW (Management and Handling) Rules, 2016 lay down the procedures and guidelines for segregation, collection, storage, transportation, processing and disposal of MSW throughout India. The rules are applicable to all the municipalities and are framed in order to make citizens well aware of their responsibilities so that they can practice guidelines for an effective management of MSW.

1.5 Review of Literature

For defining the objectives and scope in the proposed research area a detailed literature survey is carried out both in terms of theory and experimentation. A brief literature review conducted helps in providing knowledge for further innovative, safe and efficient design for MSW management.

Agarwal et al, 2005 investigated and analysed the recycling potential of MSW in the Indian capital city of Delhi. It was found that an informal sector comprising waste recyclists and a hierarchy of recyclable dealers plays an important role in the management of solid waste. Recycling of the municipal solid waste (MSW) was investigated and analyzed in the Indian capital city of Delhi. It was found that an informal sector comprising waste recyclists and a hierarchy of recyclable dealers play an important role in the management of solid waste.

Mor et al, 2006 assessed the effect of leachate percolation on the ground water samples was analyzed from unlined landfill site in Delhi. It was found that high concentrations of various physical and chemical parameters as well as heavy metals in ground water indicate that groundwater quality is being significantly affected by leachate percolation thus renders the associated aquifer unreliable for domestic water supply and other uses.

Shekhar A, 2009 gave various approaches for SWM should be compatible with the nature of a given society, and, in this regard, Asian countries are no exception. The systems are being oriented to concentrate on sustainability issues; mainly through the incorporation of 3R (reduce, reuse and recycle) technologies. However, degree and nature of improvements toward sustainability are varying and depend on the economic status of a country.

Awasthi et al, 2013 in their research revealed that the leachate contain high concentration of heavy metals. In addition, most of the heavy metals concentration in leachate is exceed the maximum permissible limit into the natural environment of materials hazardous to the aquatic environment. Rapid urbanization and population growth are largely responsible for very high increasing rate of solid waste in the urban areas, its proper management and recycling is major problems of Municipal Corporation.

Pillai et al, 2014 evaluated the effect of MSW dump site on the chemical properties of the underlying soil for the dump site at Latur. The leachate samples exceeded the standard values for disposal into surface water bodies. Soil was contaminated with varying concentrations of leachate. Various chemical parameters in the soil showed different trends with increasing leachate concentrations hence proving solid waste dumps have some effect on the Engineering and chemical properties of soil. Not only does it reduce the overall soil strength and consequently its usefulness as a foundation material, it also can result in pollution of ground water sources due to percolation of toxic and hazardous chemical.

Maiti et al, 2015 carried out a research in Dhapa solid waste dump site Kolkata. During the research leachate sample were collected and analysed for different parameters in two seasons. The laboratory test results show prevalence of high concentration of TDS, $NH4^{+}$-N, Cl^{-} and some heavy metals such as Pb and Hg in all the leachate samples. The maximum concentration of heavy metals lead and mercury for water resources have exceeded their respective permissible limits recommended by Bureau of Indian Standards (BIS). The results recommend appropriate leachate treatment before discharging it to the surrounding environment.

Kaur et al, 2015 conducted a research on waste management policies in India and concluded that lack of awareness; public-private partnership, technical knowledge, finance and long term strategy, and public motivation are major issues for solid waste management in India.

Abd EI-Salam, M.M., and Abu-Zuid, G.I., 2015 evaluated in their results the environmental impacts associated with solid waste landfilling, leachate and groundwater quality near the landfills were analyzed. The results of physico-chemical analyses of leachate confirmed that its characteristics were highly variable with severe contamination of organics, salts and heavy metals.

Gupta, A., and Rajamani, P., 2015 conducted study which deals with the toxicological effects of municipal landfill leachate on Vicia faba. The physiological responses varied as a function of leachate concentration which was further dependent on the season of leachate collection. Therefore, this study suggests that the leachate collected in all the three seasons is toxic and may pose a health effect to the general public directly or indirectly.

Parkes O, Lettieri P and Bogle IDL, 2015 performed LCA analysis to evaluate direct and indirect emissions resulting from various treatment options of MSW annually generated on site together with avoided emissions resulting from energy, materials and nutrients recovery. The outcomes of such assessments provide decision-makers with fundamental information regarding the environmental impacts of different waste treatment options necessary for sustainable waste management planning.

Ahmed and Joshi, 2016 conducted a study to have a brief understanding of the state of and challenges in MSW management in urban India. The aim of the study was to present the status of MSW and other important aspects like challenges for integrated SWM, intricacy of PPP mode, role of rag-pickers, prevailing practices of MSWM, and the rules pertaining to

waste management in India. In developing countries like India, it is important to plan and implement sustainable low cost solid waste management strategies.

Talalaj, I.A., and Biedka, P., 2016 assessed the groundwater quality near the landfill sites using landfill water pollution index. The calculated values of the LWPI allowed the quantification of the overall water quality near the landfill sites. The applied WQI can also be an important information tool for landfill policy makers and the public about the groundwater pollution threat from landfill.

The summary of literature reviews reflect that indiscriminate dumping of MSW without any prior treatment or management must be stopped and remedial measures must be adopted to stop further contamination.

1.6 Research Objectives

The main objectives of the study include:

1) To understand the existing waste management practices in Tricity of Chandigarh, Mohali and Panchkula.
2) To characterize (both physical and chemical) the municipal solid waste generated in Tricity.
3) Characterization of leachate and investigation of impact of leachate on ground water quality in the vicinity area of dumping sites of Chandigarh, Mohali and Panchkula.
4) To determine the Water Quality Index (WQI) and Leachate Pollution Index (LPI) for the present dumping sites of Chandigarh, Mohali and Panchkula.
5) To make a Life Cycle Assessment of potential municipal solid waste management strategies in Tricity.

1.7 Organization of Thesis

The first chapter of the thesis provides a brief introduction to solid waste and trend of status and existing waste management practices in India. This chapter also highlights the environmental implications of unscientific management of municipal solid waste. Further, various steps taken by Government of India to improve waste management practices are also discussed.

The second chapter deals with the detailed review of available literature and related studies carried out at national and international locations to find out the effect of solid waste dump site on environment. The chapter also outlines the objectives of the present research work.

The third chapter provides an overview of the waste management options practiced in Tricity. Recommendations to improve the existing waste management practices in Tricity and for compliance of MSW management rules in more comprehensive manner are also presented in this chapter.

The fourth chapter provides a detailed characterization (both physical and chemical) of MSW to enable suitable decision making for proper management of solid waste generated.

The fifth chapter presents environmental impact of leachate generation from the dumping sites of Tricity Leachate samples were analyzed for various physico-chemical parameters, heavy metals and toxicological analysis. It has been observed that leachate has shown high concentration of parameters examined. The chapter gives a detail of leachate pollution indexing also used to examine the pollution potential from the dumping sites.

The chapter six presents the impact of leachate generated on the ground water quality in surrounding areas. Ground water samples were collected from the vicinity areas of dumping sites were analyzed for various physico-chemical, heavy metals and microbiological parameters. It has been observed that leachate generation from dumping sites has contaminated the groundwater quality of surrounding area and there is need for leachate collection and treatment to prevent further degradation of water resources. The chapter gives detail of water quality indexing and multivariate analysis.

The chapter seven presents details of Life Cycle Assessment of potential municipal solid waste management strategies in Tricity. The study analyses the impacts of different potential waste management alternatives for Tricity using LCA approach.

The chapter eight discusses the detailed summary of the results and conclusions derived from the study. The chapter also gives the recommendations for the improvement of existing waste management practices in Tricity and also mentions the future scope of the research.

2. METHDOLOGY

2.1 Evaluation of Existing MSW Management Practices in Tricity

2.1.1 Introduction

The present study has been undertaken to review the existing waste management practices in Tricity of Chandigarh, Mohali and Panchkula. The MSW generation from the Tricity of Chandigarh, Mohali and Panchkula account for approximately 680 tons per day (TPD) of solid waste (380 TPD in Chandigarh, 150 TPD in Mohali and 150 TPD in Panchkula). The municipal corporations of Chandigarh, Mohali and Panchkula respectively are responsible for the overall management of municipal solid waste which includes storage, collection of waste from collection points and transportation to processing plant. Figure 2.1 shows the proposed Waste Management Scheme for Tricity.

2.1.2 Wasteaware Benchmark Indicators for Assessment

A system analysis of the MSW generated in Tricity has been evaluated by the '*wasteaware*' techniques to evaluate its performance. The major issues like lack of suitable data and lack of persistent data can be utilized for comparing the efficiencies of solid waste management system for different cities. In this context, '*wasteaware*' benchmark indicators were introduced which consists of both qualitative and quantitative indicators (Wilson et al, 2013; Wilson et al, 2015). Quantitative indicators comprises of Public Health-collection, Environmental controlled disposal and Resource Management – reuse, reduce and recycling (as percentages) whereas the qualitative indicators are part of governance covering user and provider inclusivity; financial sustainability; and the national policy framework and local institutions (Wilson et al, 2013; Wilson et al, 2015).

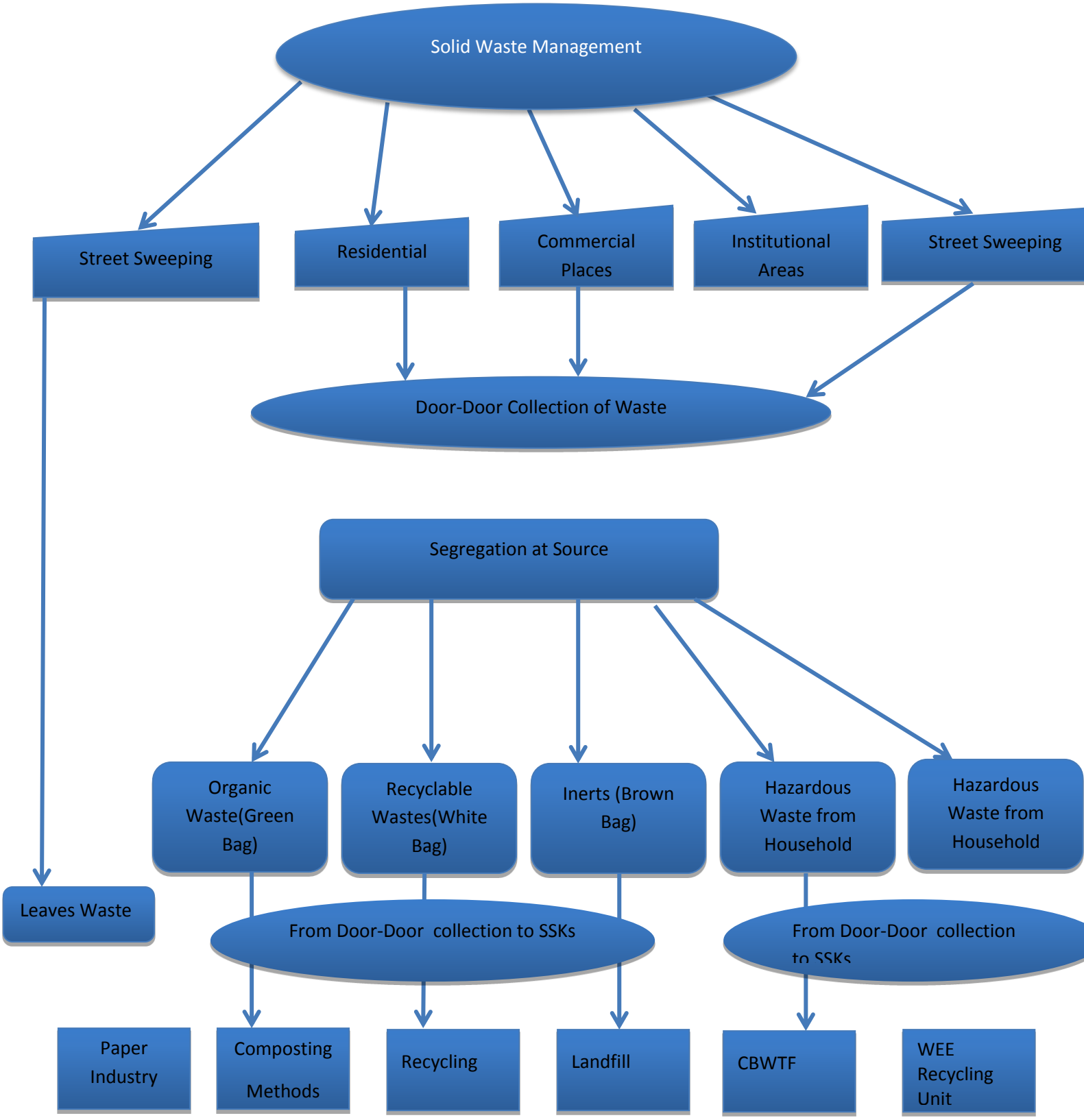


Figure 2.1: Proposed Waste Management Scheme for Tricity

2.1.3 Matrix Method of Evaluation of Existing Practices

A simple quantification method has been proposed using the matrix. The proposed grading system used in the wasteaware benchmarks is low (L), Low/Medium (L/M), Medium (M), Medium /High (M/H) and High (H), a certain weightage has been assigned to each of these. The assigned weights are (L=1, L/M=2, M=3, M/H=4, H=5).

2.2 Characterization of MSW from Tricity

2.2.1 Introduction

The composition and quantity of MSW is influenced by a number of factors like living standards, seasons, food habits, source of generation and socio-economic conditions of the area (). The study characterizes the physical and chemical properties of the MSW generated in all the three study locations for different socio-economic groups including Commercial (comm.), Low Income Group (LIG), Middle Income Group (MIG), High Income Group (HIG) and Institution (Inst.).

2.2.2 Materials and Methods

Samples from all three cities were collected from vehicles unloading waste from commercial, institutional and household waste at the dumping sites. In accordance with the method, vehicles identified from the designated regions reaching the dumping sites were selected arbitrarily throughout each day of the 10 days sampling period to have an illustrative waste stream. A total of thirty samples (n = 10 for each site) were utilized for the study purposes. All the contents in the vehicles were emptied on a plastic sheet for preventing mixing of soil or any beneath water; 1000 kg of the waste sample unloaded from the vehicles was then reduced to 100 kg in second iteration. Segregation of the waste sample was done manually with the help of workers and rag pickers.

2.2.2.1 Physical Characterization

Determination of the physical composition of MSW is highly important as it helps in ascertaining the suitable technology for implementation of an effective waste management system. The samples collected were analyzed on wet weight basis (without any prior drying of waste samples for removal of moisture) and segregated into their components. The segregated component includes paper, polythene/plastic, clothes/textiles, organics/vegetables/horticulture, rubber/leather, glass, other mixed constituents like clothing, toy and sanitary items metals and inert.

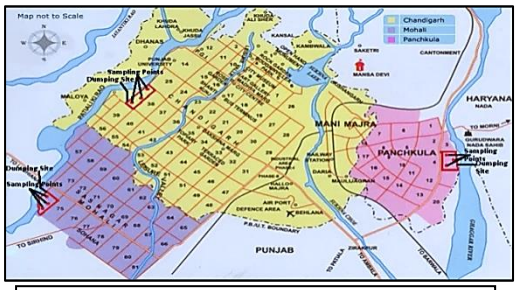
2.2.2.2 Chemical Characterization

The proximate and ultimate analysis of the MSW was also performed to determine the fraction of crustal elements and ash content of the MSW as physical characterization provides information only regarding the main component fraction present in MSW. Various analyzed parameters include moisture content, volatile matter, ash content, fixed carbon and elemental analysis (C, H, N, S and O) and gross caloric value.

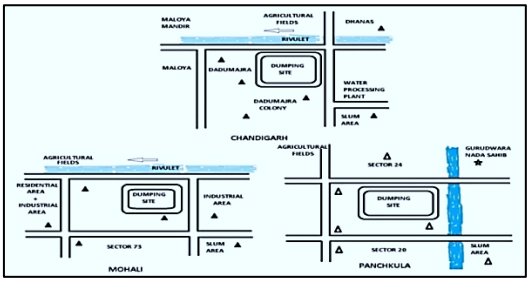
2.3 Characterization of Leachate and Assessment of its Toxicity Potential

2.3.1 Introduction

The study assesses the impact of the landfill pollution on the ground water quality of the three unlined landfill sites of Chandigarh, Mohali and Panchkula. Figure 2.3.1a shows the location of dumping sites with sampling points and Figure 2.3.1.b shows the sketch of the studied area with groundwater sampling points.



Map of Tricity showing sampling sites



Sketch of the studied area with groundwater sampling points

2.3.2 Materials and Methods

2.3.2.1 Collection of Leachate and Ground water samples

To comprehend the impact of leachate on groundwater, both leachate and groundwater samples were collected and analyzed for various water quality parameters. As the dumping site is an open dump and therefore no leachate collection facility is available at the dump site, therefore, the samples of leachate were collected randomly in and around the waste piles and mixed thoroughly to get a representative sample on the other hand groundwater samples were collected from the hand pumps and other nearby submersibles close to the solid waste dumping sites at different downstream locations (1Km, 2Km, 2.5 Km, 3Km, 4Km and 5Km) from the MSW dumping sites in the months of May-June, 2015 ; September-October, 2015 and February-March, 2016.

2.3.2.2 Analysis

Leachate samples were analyzed for various physico-chemical, biological and heavy metals including measurement of important parameters like pH, Total dissolved solids (TDS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total kjeldahl nitrogen (TKN), Ammonical nitrogen (NH_3-N), heavy metals (iron, copper, nickel, zinc, lead and chromium) chlorides, cyanides and Total coliform bacteria (TCB) and also to determine the health risks by the leachate generated *in vitro* toxicity assays using the Neuro-2a cell lines was performed. Risk assessment was also carried out to find out the potential carcinogenic health risks due to the polycyclic aromatic hydrocarbons (PAHs) which are present in the groundwater due to the percolation of the leachate.

Groundwater samples were analysed for various selected parameters like pH, total solids, ammonical nitrogen, phosphate, turbidity, biochemical oxygen demand (BOD), sulphate, total hardness (TH), calcium, magnesium, total alkalinity, nitrates, chlorides, fluorides and electrical conductivity (EC). Groundwater samples were stored in plastic and glass bottles which were thoroughly cleaned and autoclaved to remove any contamination as per standard procedure (APHA, 2017).

2.4 Leachate Pollution Index (LPI) and Water quality index (WQI) for study location

2.4.1 Introduction

The study assesses the pollution potential of leachate generated from three non-engineered landfill sites located in the Tricity region (one each in cities of Chandigarh, Mohali and Panchkula) and its possible effects of contamination of groundwater.

2.4.2 Leachate Pollution Index (LPI)

LPI signifies the level of pollution concentration of a landfill. The indexing method leads to computation of a single value which varies from **5** (*best value*) to **100** (*worst value*), which expresses the overall pollution potential due to leachate contamination in form of an increasing scale index wherein higher values indicate higher levels of pollution leading to environmental degradation (Bhalla et al. 2014; Kumar and Alappat, 2004). A total of 18 variables are generally utilized for calculation of LPI (Kumar and Alappat, 2004). These variables include pH, TDS, BOD, COD, TKN, Ammonia nitrogen, Total iron, Copper,

Nickel, Zinc, Lead, Chromium, Mercury, Arsenic, phenolic compounds, Chlorides, Cyanide and Total coliform bacteria. All the 18 parameters were assigned particular weights based on the significance level of individual pollutants as per study previously undertaken (Kumar and Alappat, 2004; Umar et al. 2010). The averaged sub-index (p_i) curves for all the pollutants were drawn to establish the relation between the leachate pollution and concentration of the parameter (Kumar and Alappat, 2004; 2009; Bhalla et al. 2014).

LPI is calculated using the equation:

$$LPI = \sum_{i=1}^{n} wipi \qquad (1)$$

Where: LPI= the weighted additive leachate pollution index,

w_i= the weight for the i^{th} pollutant variable,

p_i= the sub-index value of the i^{th} leachate pollutant variable,

If the data for all the leachate pollutant variables is not available then LPI can be calculated using the following equation:

$$LPI = \sum_{i=1}^{m} wipi \div \sum \; wi \qquad (2)$$

Where: m= number of leachate pollutant variables when data is available ($m<18, \sum wi < 1$)

2.4.3 Water Quality Index (WQI)

WQI utilizes the water quality data and helps in modification of the policies formulated by the environmental agencies (Tyagi et al. 2013). It represents the assessment of water quality through determination of physico-chemical and biological parameters of ground water (Kalra et al. 2012). A general approach for determination of WQI includes parameter selection wherein these parameters are selected based upon their impact on water quality like pH, ammonical nitrogen, turbidity, total Solids. Once the parameters are fixed, determination of sub-indices of these parameters are quantified which are finally aggregated using an aggregate indexing method using different mathematical expressions (Tyagi et al. 2013; Swamee and Tyagi, 2000).

For the considered different parameters, variations of sub-indices are generally assumed as uniformly decreasing

$$s = (1 + \frac{q}{qc})^{-m} \quad (3)$$

Where; q = quality variable;

q_c = characteristic value of q;

m = a positive number

and

Unimodal (Swamee and Tyagi, 2000; Bhalla at al. 2013).

$$s = pr + (n + p)(1 - r)(\frac{q}{q*})^n \ \div p + n(1 - r)(\frac{q}{q*})^{n+p} \quad (4)$$

Where; r = sub-index for q=0;

n and p=exponents

The parameters included for uniformly decreasing sub-indices include ammonical nitrogen and turbidity whereas parameters included for unimodal sub-indices are pH and total solids.

2.4.4 Multivariate Analysis

2.4.4.1 *Principal components analysis (PCA)*

The principal component analysis (PCA) is a procedure which identify the small variables from a large set of data which are called 'principal components' for analyzing relationships among the observed variables (Singh et al. 2004; 2008). It helps in identification of source of pollutants (Gibrilla et al. 2011) and also used to reduce the data (Guler et al. 2002; Manikandan et al. 2014).

2.4.4.2 *Hierarchical cluster analysis (HCA)*

Hierarchical cluster analysis (HCA) is the most common and widely used multivariate statistical analysis method in environmental studies (Singh et al. 2016) as it indicate groupings of samples by ranking or linking inter-sample similarities in data set creating a cluster tree or dendogram (Diaz et al., 2002).

2.5 Life Cycle Assessment potential strategies for better MSW management in study locations

2.5.1 Introduction

Life cycle assessment (LCA) is a tool to quantify environmental burdens associated with products or activities throughout their life cycle (Cumar and Nagarajan, 2011).The study analyses the impacts of different potential waste management alternatives for Tricity using LCA approach. Five potential scenarios of scientific solid waste management are analyzed. The impact categories analyzed are global warming, acidification, eutrophication and human toxicity.

2.5.2 Materials and Methods

2.5.2.1 MSW management scenarios

Scenario 1: Baseline scenario- Business as usual (BAU):- It represents the present MSW management practice in Tricity.

Scenario 2: Material Recovery Facility_Sanitary Landfilling (MRF_SLF):- This scenario assumes that 20% of the recycled materials are recycled and rest of the waste is sanitary landfilled in place of present open dumps. The scenario also assumes that 50% biogas released from the landfill would be collected and then used for electricity generation and rest escape to atmosphere.

Scenario 3: Material Recovery Facility _Composting_ Sanitary Landfilling (MRF_COM_SLF):- Emphasis in this scenario is on biodegradation of MSW. The Scenario assumes 20% of the recycled material is recycled through MRF and 80% of the biodegradable (40%) composted (COM) and remaining fraction is sent to disposal into sanitary landfill.

Scenario 4: Material Recovery Facility _Composting_ Anaerobic Digestion_ Sanitary Landfilling (MRF_COM_AD_SLF):- 20% recycled through MRF +60% composting +20% anaerobic digestion and rest sent to landfill.

Scenario 5: Material Recovery Facility _Composting _ Incineration (MRF_COM_INC):- 20% recycled through MRF +40% composting and rest is sent to incineration with electricity production.

2.5.2.2 Sensitivity analysis to recycling rate

In the study, the LCA was accomplished using the simapro software version 8.3.0 and expressed with the Eco-Indicator 99 (H) and Eco-Invent method. The sensitivity analysis identifies sensitive parameters, that is, whether a small change in input parameter would induce a large change in impact category. The input parameters for sensitivity analysis focus on the recycling rate.

3. RESULTS AND DISCUSSIONS

3.1 Current Status of MSW Management Practices in Tricity

The study reports that the daily average MSW production in Tricity is 680 tons (Chandigarh 380 tons/day; Mohali 150 tons/day; Panchkula 150 tons/ day). Chandigarh city reports a collection efficiency of 90% but for Mohali and Panchkula it is only 70% and 60% respectively, which is very poor. Delay in waste collection leads to degradation of waste and rag picking activities. It is suggested that daily door-to-door collection of waste should be done. The main drawback for such conditions is the location of the bins. The present landfill sites in all the three cities of Tricity have no proper lining system to control the percolation of leachate in the groundwater.

3.1.1 Evaluation using Wasteaware benchmark indicators for sustainable waste management

The 'waste-aware' benchmark indicators were generated for Tricity and are presented in Table 3.1.1. It is observed that Lahore city which has almost eight times the population of Chandigarh almost generates twice the amount of waste per capita due to higher population density. Interestingly, this is also observed for Mohali city which has a higher population generate lower waste per capita than Panchkula city which has a lower population. Further, comparison of the '*wasteaware*' benchmarks parameters for Mohali, Panchkula, Chandigarh, Surat and Lahore shows that Chandigarh, Mohali and Surat have very good collection efficiencies as compared to Panchkula and Lahore which showed 'low-medium' and 'medium' index on wasteaware benchmark indicators respectively. The major difference between Mohali, Panchkula, Chandigarh, Surat and Lahore is in the disposal methods and in the efficiency of *3R method*. While Surat scores a 'Low/Medium' index for environmental controlled waste treatment and disposal method as reported earlier (Wilson et al, 2013), Mohali and Panchkula scores 'Low' index similar to studies carried out in other tier – II cities of India including Chandigarh (Rana et al, 2015) and Lahore (Wilson et al, 2015) scores in the same category. This is because the disposal sites are unsanitary landfill in nature. Further, there is no lining provided at the landfill site to prevent the percolation of leachate in groundwater thereby contributing to environmental hazard.

Table 3.1.1 Comparison of Wasteaware parameters for Tricity with other tier –II cities of India and Asia.

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
Background Information of the City							
B1	Country Income Level	World Bank Indicator Level	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle	Lower-Middle
		GNI per Capita	$1,420	$1,420	$1,420	$1,420	$1,140
B2	Population of the City	Total Population of the City	1,055,450	9,86,147	5,61,293	4,600,000	8,160,000
B3	Waste Generation	MSW Generation (tons/year)	13,5050	37,595	54,750	45,6250	1,916,000
W1	Waste per Capita	MSW per capita (kg per year)	128	38.12	97.54	119	219
W2	Waste Composition	3 key fractions – as % wt. of total waste generated					
W2.1	Organic	Organics (food and green wastes)	52%	55%	-	54%	65%
W2.2	Paper	Paper	6%	5%	-	8%	2%
W2.3	Plastics	Plastics	7%	4%	-	10%	12%
1.1	Public health – Waste collection	Waste collection coverage	90%(M/H)	90%(M/H)	60%(L/M)	95%(M/H)	77%(M)
1C		Quality of waste collection service	90%(M/H)	75%(M)	60%(L/M)	95%(M/H)	58% (M)
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	30%(L)	30%(L)	30%(L)	55%(L/M)	8%(L)
2E		Degree of environmental protection in waste treatment and disposal	L (0%)	L (0%)	L (0%)	L/M (37%)	L/M (37%)
3	3Rs – reduce, reuse and recycling	Recycling rate	0% (L)	0% (L)	0% (L)	30% (L)	35% (M)
3R		Quality of 3Rs provision	L (17%)	L (10%)	L (12%)	L/M (29%)	L (17%)
Governance Factors							
4U	User inclusivity	User inclusivity	M (75%)	M (75%)	M (74%)	M (80%)	L/M (37%)

4P	Provider inclusivity	Degree of provider inclusivity	M (78%)	M (76%)	M (75%)	M (82%)	L/M (50%)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	L/M (60%)	L/M (60%)	L/M (60%)	L/M (60%)	L/M (29%)
6L		Degree of institutional coherence	M (75%)	M (75%)	M (75%)	M (77%)	M/H (62%)

3.1.2 Quantification of indicators using Matrix Method of Evaluation

Using the methodology of matrix method the weights were assigned for the respective indicators and has been presented in Table 3.1.2a. The final scores obtained using the matrix methodology has been summarized in Table 3.1.2b. The matrix method for evaluation showed the best possible results for Surat city with an overall score of 52%, being classified as L/M category. Qualitative and Quantitative parameters for Surat were almost of equal score (Quantitative parameters = 50%, Qualitative parameters = 55%). In contrast, the quantitative parameters were significantly less than the qualitative parameters for Chandigarh, Mohali and Panchkula. The overall classification of the three cities was in the low categories. Interestingly, governance factors for all the Indian cities were equal with 55% of weightage. Interestingly, no recycling facilities exist for Chandigarh, Mohali and Panchkula.

Table 3.1.2a: Weightage Assignment for evaluation using matrix method.

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
Quantitative Indicators (Public Health, Environmental Control, 3R)							
1.1	Public health – Waste collection	Waste collection coverage	90%(M/H) (4)	90%(M/H) (4)	60%(L/M) (2)	95%(M/H) (4)	77%(M) (3)
1C		Quality of waste collection service	90%(M/H) (4)	75%(M) (3)	60%(L/M) (2)	95%(M/H) (4)	58% (M) (3)
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	30%(L) (1)	30%(L) (1)	30%(L) (1)	55%(L/M) (2)	8%(L) (1)
2E		Degree of environmental protection in waste treatment and disposal	L (0%) (1)	L (0%) (1)	L (0%) (1)	L/M (37%) (2)	L/M (37%) (2)
3	3Rs – reduce, reuse and	Recycling rate	0% (L) (1)	0% (L) (1)	0% (L) (1)	30% (L) (1)	35% (M) (2)

3R	recycling	Quality of 3Rs provision	L (17%) (1)	L (10%) (1)	L (12%) (1)	L/M (29%) (2)	L (17%) (1)
Qualitative Indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	M (75%) (3)	M (75%) (3)	M (74%) (3)	M (80%) (3)	L/M (37%) (2)
4P	Provider inclusivity	Degree of provider inclusivity	M (78%) (3)	M (76%) (3)	M (75%) (3)	M (82%) (3)	L/M (50%) (2)
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	L/M (60%) (2)	L/M (60%) (2)	L/M (60%) (2)	L/M (60%) (2)	L/M (29%) (1)
6L		Degree of institutional coherence	M (75%) (3)	M (75%) (3)	M (75%) (3)	M (77%) (3)	M/H (62%) (4)

Table 3.1.2b: Summary of scores obtained using matrix method

No.	Category	Indicator	Chandigarh City Results	Mohali City Results	Panchkula City Results	Surat City Results	Lahore City Results
Quantitative Indicators (Public Health, Environmental Control, 3R)							
1.1	Public health – Waste collection	Waste collection coverage	4	4	2	4	3
1C		Quality of waste collection service	4	3	2	4	3
2	Environmental control – waste treatment and disposal	Controlled treatment and disposal	1	1	1	2	1
2E		Degree of environmental protection in waste treatment and disposal	1	1	1	2	2
3	3Rs – reduce, reuse and recycling	Recycling rate	1	1	1	1	2
3R		Quality of 3Rs provision	1	1	1	2	1
Total Score (Quantitative Indicators)			12	11	08	15	12
Maximum Score			30	30	30	30	30
Weightage (%)			**40**	**37**	**27**	**50**	**40**
Qualitative Indicators (Governance Factors)							
4U	User inclusivity	User inclusivity	3	3	3	3	2
4P	Provider inclusivity	Degree of provider inclusivity	3	3	3	3	2
6N	Sound institutions, proactive policies	Adequacy of national SWM framework	2	2	2	2	1
6L		Degree of institutional coherence	3	3	3	3	4

Total Score (Qualitative Indicators)	11	11	11	11	9
Maximum Score	20	20	20	20	20
Weightage (%)	**55**	**55**	**55**	**55**	**45**
Total Score (Overall)	12+11 = 23	11+11 = 22	08+11 = 19	15+11 = 26	12+09 =21
Total Maximum Score	30+20 =50	30+20 =50	30+20 =50	30+20 =50	30+20 =50
Overall Weightage (%)	**46**	**44**	**38**	**52**	**42**

3.2. Physical and Chemical Characterization of MSW

The results of physical and chemical characterization of MSW from Chandigarh, Mohali and Panchkula are presented in Table 3.2a and 3.2b.

Table 3.2a: Physical Characterization of MSW

Components	**Commercial (%)**			**HIG*(%)**			**MIG*(%)**			**LIG*(%)**			**Institutional (%)**		
	CHD	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**	**CHD**	**MOH**	**PKL**
Density (Kg/m^3)	580±4.1	480±7.6	390±5.7	490±8.7	395±2.9	380±2.1	500±2.4	430±8.7	490±6.1	550±8.7	550±8.8	487±7.8	384±2.99	470±4.6	410±7.6
Compostable*	56.4±4.46	52.6±2.88	49.4±3.56	48.9±3.67	46±6.1	38.8±3.2	59±4.6	53.9±2.56	49.1±8.2	58.1±2.9	54.9±1.4	51.5±3.4	35.6±2.1	26.4±2.76	24.1±3.34
Paper/ Cardboard*	4.2±1.8	2.5±1.9	3.5±1.9	7.0±2.1	7.8±1.8	7.3±0.7	5.2±0.77	4.5±2.98	5.2±3.3	5.1±3.8	4.6±2.9	3.8±1.40	8.6±2.4	7.4±1.7	7.3±6.8
Plastics/ Polythene*	6.6±1.88	7.3±3.44	6.4±2.8	8.2±6.7	8.0±1.44	8.5±2.9	6.2±1.1	5.7±1.7	5.9±0.77	5.1±1.16	4.7±0.2	4.6±1.80	10.6±3.9	9.4±8.9	9.9±7.2
Glass*	0.4±1.1	0.2±1.61	0.8±1.09	1.8±0.6	1.9±4.10	1.22±1.8	1.4±2.1	1.0±2	1.4±0.45	0.1±1.4	0.4±3.1	0.1±1.68	4.3±2.75	3.9±0.23	3.7±1.5
Rubber/ Leather*	0.6±1.72	0.1±0.16	0.2±0.17	2±5.23	1.9±0.03	1.7±1.2	0.5±6.1	0.7±0.04	0.53±2	0.9±1.56	0.5±0.02	0.4±1	4.5±0.45	3.2±0.23	3.1±0.01
Metals*	0.2±0.34	1.0±1.78	0.6±1.1	0.1±0.03	0.1±1.6	0.5±1.7	0.1±0.3	0.1±0.03	0.2±0.1	1±0.02	0.1±1.7	0.1±0.01	2.7±0.01	2.0±1.3	2.0±0.4
Inerts[a]*	28.5±9.2	29.4±4.66	29±9.66	29±2.3	30.1±9.6	30.8±5.7	22±1.7	25±1.58	25.2±4.3	28.7±1.34	32.2±7	33±6.1	26.9±5.62	26.3±7.9	24.3±6.6
Miscellaneous[b]*	3.5±1.6	7.6±1.56	10.1±5.84	3±2.87	4.2±3.89	11.7±3.3	5.6±1.56	9.3±5.29	12.5±7.4	1±3.3	2.6±1.7	7±5.9	7.6±6.6	21.3±2.19	25.6±4.57

Table 3.2b: Chemical Characterization of MSW

Components	Commercial (%)			HIG*(%)			MIG*(%)			LIG*(%)			Institutional (%)		
	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL	CHD	MOH	PKL
Proximate Analysis															
Moisture Content	59±7.8	49±5.66	44±5.2	49±3.9	44.6±2.1	37±1.76	42±2.44	43.6±7.1	38±1.77	58.9±8.2	57.7±9.26	44±6.71	42.01±6.66	34±5.21	35±7
Volatile matter	17.7±4.5	21±4.54	21.6±5	25.8±3.2	28.65±2.3	28.21±2.2	28±7.65	25.1±6.4	25.9±4.06	17±2	17.6±6.1	25±5	24.8±4.10	24.9±2.5	25.3±4.65
Ash content	22.4±5.7	28.8±4.1	30.2±4.8	24.7±6.56	24.95±4	29±6.1	26.4±6.70	28.5±7	28.8±4.98	23.3±4	21.6±6.1	26.2±7.8	32.9±3.4	33.7±7.5	35.3±8.5
Fixed carbon	1.0±4	1.99±0.1	4.2±3.8	0.8±6	1.82±7.12	5.79±1.66	3.67±0.76	2.8±5.23	7.3±0.6	1.0±1.89	3.1±5.6	5.7±5	0.5±6.59	7.6±4.56	4.4±7.4
Gross Calorific value	2200±41.8	2186±128.6	2218±324	2508±145	2208±206	1500±291.5	1729±160.2	1421±96.1	1540±116	1008±56.8	1005±88	1123±138	2200±459	2185±233	1329±132
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ultimate Analysis															
Carbon	33.6±2.03	30±30.2	29.8±2.30	37±3.61	36.01±4.18	35.3±4.32	34.4±6	32.9±5.45	32.19±2.32	32.9±8.9	34.55±7	32±8.5	33±2.13	35.9±0.66	30±2.56
Hydrogen	3.90±1.45	4.56±1.34	4.2±2.2	4.6±2.98	4.08±±1.76	3.40±1.66	6.6±2.67	4.9±6.52	5±2	3.9±1.77	4.0±6.12	4.56±2.34	3.10±1.77	3.78±1.43	4.09±1.23
Sulphur	1.0±0.001	0.001±0.1	ND	ND	ND	ND	ND	ND	ND	ND	0.001±0.008	0.001±0.01	ND	ND	ND
Nitrogen	1.2±1.76	1.4±1.45	1.06±0.001	1.4±1.66	1.39±0.12	1.2±0.08	1.5±6.3	1.48±2.30	1.2±1.11	1.35±0.67	1.49±1.34	1.3±2.66	1.3±2.45	1.89±3.91	1.08±7
Oxygen	12.6±6.43	12.9±6.22	14.2±7.87	12.5±8	10±2.61	10.01±1.58	6.9±3.4	5.8±5.45	6.2±2.33	14.1±6.43	13.3±4.21	14±6.41	10.99±2.56	9.06±0.04	11.2±1.12
Mineral matter	47.7	51.2	51.7	44.5	48.5	50.09	50.6	54.9	55.4	47.7	46.9	48.1	51.6	49.3	53.1

It was observed that due to higher percentage of compostable and inert fractions the bulk density of wastes from all the three cities was high. The density of the waste of Chandigarh, Mohali and Panchkula was reported to be 500.8 kg/m3, 465 kg/m3 and 432 kg/m3

respectively. It was observed that the major fraction of the MSW from the various socio-economic groups of the three cities of Chandigarh, Mohali and Panchkula includes organic material ranging from 24.1 to 59 % of the total MSW followed by inert with composition ranging from approximately 22–33%. The MSW collected from the LIG areas contained maximum organic fraction for all the three cities. The physical characterization results show that the inorganic fraction of the MSW in Chandigarh, Mohali and Panchkula (Tricity) were found to be 17.4, 15.1 and 15.7% respectively. It was observed from the results that major fractions of inorganics were generated from commercial, institutional and HIG areas suggesting the use of more packaged and disposable products in these sectors.

Wet moisture content of the MSW for Chandigarh, Mohali and Panchkula were observed to be in range of 42–59%, 34–57.7% and 35–44% respectively. The combined average ash content of low-income group from all the three cities was reported to be 23.7% (23.3% in Chandigarh, and 21.6% in Mohali and 26.2% in Panchkula).

The calorific value of the MSW of Chandigarh, Mohali and Panchkula was found to be significantly high in HIG (2508 kcal/kg in CHD, 2208 kcal/kg in MOH and 1500 kcal/kg in PKL) followed by the commercial area (2200 kcal/kg in CHD, 2186 kcal/ kg in MOH and 2218 kcal/kg in PKL) and lowest in LIG (1008 kcal/kg in CHD, 1005 kcal/kg in MOH and 1123 kcal/kg in PKL). This is primarily due to the presence of higher combustible fractions of waste in HIG and commercial sector in comparison to LIG wherein more organic fraction and higher moisture content was observed. The elemental composition analysis indicated higher average concentration of C (34.18% in CHD, 33.8% in MOH and 31.9% in PKL) followed by O (11.41% in CHD, 10.2% in MOH and 11.1% in PKL), H (4.42% in CHD, 4.2% in both MOH and PKL) and N (1.35% in CHD, 1.53% in MOH and 1.1% in PKL).

Based on the MSW characterization from Chandigarh, Mohali and Panchkula, it is suggested that a single existent technology like RDF cannot lead to complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste, and hence for these cities a combination of composting vermicomposting and bio-methanation plant, would help in achieving a better solid waste management system.

3.3. Leachate and Ground water Characteristics

3.3.1 Physico-Chemical and biological characteristics

The physical, chemical and biological characteristic of the leachate and ground water samples collected during all the three samplings from the dumping sites of Chandigarh, Mohali and Panchkula are summarized in Table 3.3.1a and 3.3.1b respectively. The average pH of the leachate samples from all the three dumping sites over the entire monitoring campaign varied from 9.2 for Chandigarh and 8.9 for Mohali and Panchkula. It was observed that TDS varied in the ranges of 3590 to 3669 mg/L for samples from Chandigarh dumping site, 3161-3290 mg/L for Mohali leachate samples and 3048 to 3100 mg/L for Panchkula leachate samples. The COD varied in the range of 19930 to 19961 mg/L for Chandigarh, 17323 to 17968 mg/L for Mohali and 18208-19920 mg/L for Panchkula leachate samples over the entire monitoring campaign. Similarly, the BOD values were within the ranges of 360 to 425 mg/L for Chandigarh, 470 to 510 mg/L for Mohali and 310 to 370 mg/L for Panchkula over the same monitoring campaign. The concentration of NH_3-N in all the three dumping sites was high ranging amidst 1150 to 1210 mg/L for Chandigarh, 1190 to 1328 mg/L for Mohali samples and 1010 to 1030 mg/L for Panchkula samples over the monitoring campaign. This is primarily due to decomposition of the organic waste releasing to production of biogas with a high fraction of ammonia gas (Mor et al. 2006; Halim et al. 2010). The presence of lead, nickel and very low concentration of cadmium was also reported. Presence of heavy metals in the leachate samples is attributed to the unsegregated MSW in the dumping sites (Kale et al. 2010; Kolekar et al. 2016). Very high concentrations of TCB were found in all the leachate samples from the three dumping sites.

Table 3.3.1a: Leachate Characteristics

Parameters	Chandigarh			Mohali			Panchkula			Standards for Disposal		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**Inland surface water**	**Public sewers**	**Land disposal**
pH	9.6	9.1	9.0	8.9	9.0	9.0	8.6	9.1	9.0	**5.5-9.0**	**5.5-9.0**	**5.5-9.0**
TDS	3590	3669	3669	3161	3280	3290	3048	3100	3100	**2100**	**2100**	**2100**
BOD	360	420	425	470	490	510	310	360	370	**30**	**350**	**100**
COD	19930	19950	19961	17323	17940	17968	18208	19910	19920	**250**	-	-
NH_3-N	1150	1200	1210	1190	1239	1328	1010	1022	1030	**50**	**50**	-
Total Fe	11.2	12.2	12.1	7.72	7.80	7.95	8.83	8.89	8.88	-	-	-
Cu	3.72	3.80	3.66	3.32	4.90	4.85	2.23	2.40	2.40	**3.0**	**3.0**	-
Ni	0.98	0.98	0.96	0.77	0.99	0.99	0.87	0.87	0.88	**3.0**	**3.0**	-
Zn	10.41	11.60	12.2	8.4	8.6	8.7	8.39	8.41	8.60	**5.0**	**15**	-
Pb	0.64	0.66	0.70	0.07	0.07	0.08	0.11	0.19	0.20	**0.1**	**1.0**	-
Cr	0.14	0.16	0.20	2.47	3.20	3.20	0.75	0.89	0.90	-	-	-
Cl^-	2136	2230	2320	1659	1780	1786	2012	2100	2122	**1000**	**1000**	**600**
TCB	8×10^7	8×10^7	10×10^7	7×10^7	8×10^7	7×10^6	9×10^6	9×10^7	9×10^6	--	-	-

Table 3.3.1b: Ground water Characteristics

Parameters	X-distance(Km)	Chandigarh			Mohali			Panchkula			Standards	
		1	2	3	1	2	3	1	2	3	WHO	BIS
pH	1	7.8	9.1	9.1	8.8	8.9	9.2	7.8	7.8	8.1	-	6.5-8.5
	2	7.6	8.2	8.3	8.4	8.3	8.3	7.6	7.6	7.7		
	2.5	7.3	8	8	8	7.9	7.9	7.5	7.5	7.5		
	3	7.1	7.9	7.96	7.9	7.7	7.2	7	7.2	7.3		
	4	7.2	7.4	7.7	7.9	7.6	7	6.6	6.6	6.7		
	5	6.8	7.2	7.1	7.6	6.6	6	6	6	6		
TSS	1	643.2	680.1	687	783.3	788.1	789	582.4	590	592.1	-	500
	2	1191	1200	1200	626.7	642	650	577.6	531.2	530		
	2.5	677.7	770.2	787	597.7	599	599	550	500	500		
	3	597.7	600.9	632.1	550	562.7	568.1	491	489.2	460		
	4	492.6	510	517	494	500	500	376	299.7	299		
	5	482.6	550	555	492	521.9	530.1	330	249.6	236.1		
Ammonical Nitrogen (NH_3-N)	1	1.36	1.4	1.41	0.77	0.96	1.22	1.68	0	0		0.5
	2	0.96	0.98	0.99	0.13	0.27	0.9	0.78	0.79	0.8		
	2.5	0.38	0.39	0.39	0	0	0	0.15	0.15	0		
	3	0.21	0.3	0.31	0	0	0	0	0	0		
	4	0.2	0.22	0.27	0	0	0	0	0	0		
	5	0.1	0.19	0.2	0	0	0	0	0	0		
Phosphate	1	0.7	0.9	0.99	0	0	0	0.007	0.007	0.008		
	2	0.06	0.09	0.09	0	0	0	0.006	0.99	0		
	2.5	0.04	0.06	0.06	0	0	0	0.001	0.998	0		
	3	0	0	0	0	0	0	0	0	0		
	4	0	0	0	0	0	0	0	0	0		
	5	0	0	0	0	0	0	0	0	0		
Turbidity	1	10	10	9	9	10	10	10	10	10	-	1
	2	7	7	7	9	9	9	10	10	10		
	2.5	6	7	8	8	9	10	9	9	9		
	3	4	6	6	8	8	8	7	7	7		
	4	2	4	5	7	8	8	7	8	8		
	5	2	2	3	6	7	7	4	4	3		
	1	530	610	620	535	600	600	520	580	600		

Biochemical Oxygen Demand (BOD)	2	410	440	440	410	440	470	505	550	590		**5**
	2.5	320	350	370	330	360	360	420	460	490		
	3	290	310	360	310	330	350	310	390	390		
	4	250	300	310	290	330	340	220	270	270		
	5	240	290	320	210	280	300	210	220	230		
Sulphate	1	75.19	87.2	89.1	52.9	57.3	64	35.6	46.2	59.9		**200**
	2	75.17	80.15	87.5	52	54.1	61.6	35.1	44.7	59.1		
	2.5	74.6	80.1	87.2	50	51.6	61	34.3	42.6	58.7		
	3	74.2	75.5	82	46.9	50.09	59	32.7	39.9	48.1		
	4	73.9	77.2	80.1	46.1	47.1	56.1	30.1	36.3	44.2		
	5	73.1	76.4	79	40.2	41.3	50	30	33	43.9		
Total Hardness (TH)	1	280	355	492	220	296	335	210	218	290	**-**	**300**
	2	260	335	340	215	290	320	208	210	265		
	2.5	255	310	310	202	275	310	195	200	240		
	3	235	275	300	195	200	300	160	182	232		
	4	230	260	265	190	185	298	142	160	225		
	5	210	225	240	190	180	272	115	145	200		
Calcium (Ca)	1	40.2	65.1	97.8	56.7	78.1	94.6	59.2	68.4	89.9		**75**
	2	37.3	60.2	95.1	52.1	72.4	92.1	56.5	66.5	89		
	2.5	30	58.7	90	50	68.6	92	53.8	64.8	86.2		
	3	28.5	58.1	84.6	50	50	88.3	53.6	62.9	84.3		
	4	27.6	58	82.8	40.8	46	82.2	40.5	60.6	82.1		
	5	27.4	58	80	36.6	41.8	82	36.6	56.5	80.9		
Magnesium (Mg)	1	83.1	88	95.5	82.1	94.6	96.1	77.6	86.1	89.8		**30**
	2	80.9	86.3	94.2	80.1	92.9	90.9	74.5	85.3	86.9		
	2.5	75.6	83.9	93.8	80	91.1	88.6	72.9	82.6	86.3		
	3	75	82	93.6	77.1	90	86.9	71	80.8	84.2		
	4	72.8	80	92.1	74	86.3	84.1	67.5	77.7	83.6		
	5	71.7	77.7	90.9	68.6	86.1	82	61.6	74.1	80.1		
Total Alkalinity (TA)	1	484	492	524	388	428	464	312	365	396	**-**	**200**
	2	481	490	500	386	425	462	310	361	391		
	2.5	390	485	486	380	418	455	290	350	382		
	3	392	450	464	345	400	440	276	325	375		
	4	390	410	443	332	395	425	252	308	370		
	5	386	395	424	325	390	419	236	300	358		
Nitrates	1	4.7	9.2	28.7	5.5	6.9	15.9	6	8.8	21.2	**50**	**45**
	2	3.2	9.2	20.1	5.1	6.6	15.8	5.4	7.6	21		
	2.5	3	9.0	20	4.8	6.2	15.0	5	7.2	17.6		
	3	2.9	8.6	17.1	4.6	6.0	14.2	4.9	7	17.1		

	4	2	8.3	11.9	4.0	5.6	14.1	4.6	6.9	16.9		
	5	1.8	8.0	10.9	3.9	5.2	11.3	4.2	6.8	16		
Chlorides	1	86.1	93.2	114.2	88.9	101.7	111	79.8	88.4	95.4	**250**	**250**
	2	84.9	90.9	107	87.3	100	107.6	75.5	86.9	94.3		
	2.5	83.2	90	98.9	86.9	99.1	101	73.1	83.6	93.8		
	3	81.7	88.7	96.4	86.3	94.6	98	70.9	82	93.6		
	4	80.9	86.9	93.6	83.1	93.2	95.6	69.6	81.7	93		
	5	80	86.3	91.7	80.8	91.2	90.8	67.1	80	90.1		
Fluorides	1	0.1	0.1	0.06	0.07	0.1	0.1	0.15	0.18	0.18	**1.5**	**1.0**
	2	0.01	0.07	0.07	0.01	0.0	0.1	0.1	0.10	0.9		
	2.5	0.03	0.174	0.18	0.09	0.1	0	0.01	0.1	0.01		
	3	0.03	0.13	0	0.01	0.1	0.1	0	0	0		
	4	0.06	0.1	0.01	0	0.0	0	0	0	0		
	5	0	0	0	0	0.01	0	0	0	0		
EC	1	1005	1059	1861	498.2	562.2	597.7	582.4	624.9	720.1	**-**	**300**
	2	1000	1045	1840	493.8	558	597.1	580	619	713		
	2.5	992	1040	1822	493.6	550	593.6	577.5	613.6	709.1		
	3	981	1025	1812	477	547.6	592.1	575.2	609.1	700.6		
	4	980	1000	1811	472	542.7	586	568.1	600	692		
	5	976	1000	1802	466.6	540	580	566.7	598.3	686		

The physico-chemical and biological characteristics of the groundwater samples collected were also compared to the WHO and BIS standards for drinking water quality. The averages pH values for all the ground water samples from Chandigarh, Mohali and Panchkula at various distances were 7.7, 7.8 and 7.1 respectively. Electrical conductivity ranges from 976-1861 µS/cm in Chandigarh, 466.6-593.6 µS/cm in Mohali and 566.7 -713 µS/cm. High conductivity values in all the samples specify the substantial amount of dissolved ions due to contamination from the leachate (Mor et al. 2006; Manikandan et al. 2014). Total Solids (TSS) aids in determining the salinity and general quality of water. Average concentration of TSS in all the samples from Chandigarh, Mohali and Panchkula were found to be 710 mmho/cm, 600 mmho/cm and 455 mmho/cm respectively. High TSS values reported in almost all the samples of ground water from all the three cities. BOD was reported in all the groundwater samples indicating the effect of percolation of leachate on the aquifer. Organic contamination due to leachate was indicated by the presence of ammonical nitrogen. Average values of ammonical nitrogen range from 0.241-0.57 mg/l and were reportedly higher in ground water samples from Chandigarh and Mohali. Hardness of samples varies from 142 –

492 mg/l. Many samples of ground water from Chandigarh and Mohali areas shows that source water is 'Very Hard'; above 300 mg/L of $CaCO_3$ (WHO 2008; BIS 10500 2012) . All other ground water samples are 'Moderately Hard'; lies between 75-150 mg/L of $CaCO_3$ (WHO 2008; BIS 10500 2012). The average total alkalinity from all the three areas ranges from 331-450 mg/l. Reported values of alkalinity are more than the desirable limit in all the samples. Concentration of sulphate ranges from 73.1- 89.1 mg/l for Chandigarh, 40.2-64 mg/l for Mohali and 30-59.9 mg/l for Panchkula which is much below than the WHO standard limit of 250mg/l. The samples reported very low concentration of nitrate ranging from 8.37-10.2 mg/l, high concentration indicates the impact of leachate and may lead to methaemoglobinemia. Values of chloride varies between 80-114.2 mg/l for Chandigarh, 80.8-111 mg/l for Mohali and 67.1-95.4 mg/l for Panchkula, high concentration of chlorides indicates the groundwater contamination due to the percolation of domestic effluents, septic tanks (Mor et al. 2006). The average fluoride concentration for all the three cities of Chandigarh, Mohali and Panchkula were found to be less than the standard permissible limits and ranges from not detectable (ND) to 0.096mg/l.

Contamination of ground water samples in all the three cities of Chandigarh, Mohali and Panchkula is owed to the percolation due to leachate. Leachate percolation in the ground water can be a result of composition of leachate, rainfall, depth and distance from the source of pollution (Mor et al. 2006; Abd EI-Salam et al. 2015). Ground water samples collected from the close vicinity of dumping sites were found to be more contaminated than that of the farther away samples. This can be attributed to the fact that the gravitational movement of viscous fluid like leachate is hindered due to mass of solid soil matter (Mor et al. 2006) and with increasing time leachate penetrates deeper and spread over long distances. The ground water quality improves with the increase in the distance of the sampling sites from the source of pollution i.e. dumping sites.

3.3.2 Leachate Induced cytotoxic effects on Neuro-2a cell line

The effect of leachate samples on viability of Neuro-2a cell line was evaluated using MTT assay. A dose-response relationship was worked out by adding the positive control and test samples to different dilutions. Cell viability was expressed as percentage of the corresponding control (0.5%v/v Milli-Q). The sigmoid dose response curves for the samples were plotted which helped to describe the change in effect on an organism at different level of exposure, and the EC_{50} values were derived from the curve fitting linear regression model

equation (Giannapas et al., 2012; Thakur et al., 2015; Das et al., 2012). The cell viability in terms of MTT assay derived EC_{50} values (Table 3.3.2) showed the percentage of cytotoxicity of test samples. At the 50% concentration toxicity to the Neuro-2a cells from Mohali leachate showed 6.81% as compared to that of Chandigarh and Panchkula leachate (15.46% and 9.9% respectively). The overall results of MTT assay suggest that the landfill leachate from three sites significantly contained cytotoxic compounds. Some compounds found in leachate like phenanthrene, anthracene, pyrene have cellular proliferative effect (Das et al., 2012; Kaisarevic et al., 2009).

Table 3.3.2: MTT EC_{50} values of leachate samples

Treatments[a]	**MTT EC_{50}**[b]	**R^2 (EC_{50})**
Chandigarh Leachate	15.46	0.9372
Mohali Leachate	6.81	0.9617
Panchkula Leachate	9.99	0.7549

3.3.3 Human risk assessment due to PAHs present in leachate

To estimate potential adverse effects on humans and the environmental receptors a hypothesis was made in which an accidental leachate was release into the groundwater resulting in 1:100 dilutions of the leachate (Butt et al., 2013; Baderna et al., 2011). The concentration of carcinogenic PAHs as specified by BaP TEQ's was found in the range from 32.4972×10^{-2} to 78.2571×10^{-2} mg/lt. The cancer risk (CR) varied from 2.90×10^{-4} to 7.00×10^{-4}. The value of CR based on the data for toxicological ranking of leachate is ML>PL>CL. The cancer risk measured due to PAHs did not exceed the risk threshold under the present conditions however the toxic effects due to other organics as well as inorganic contaminants as specified in the results of the current study cannot be neglected. The absence of any engineered barriers and the improper leachate collection system can result in the release of cocktail of chemicals present in leachate which contaminate surrounding soil and ground water (Andrews et al., 2012).

3.4 Leachate Pollution Index (LPI) and Water quality index (WQI) for study location

3.4.1 LPI

In the present study, out of 18, only 13 significant parameters were determined as data for all parameters was not available, The LPI values of Chandigarh, Mohali and Panchkula dumping sites are reported in Table 3.4.1a, 3.4.1b and 3.4.1c respectively. The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water (Kumar and Alappat, 2005). Higher values of LPI signify that leachate produced from all these three dumping sites of Chandigarh, Mohali and Panchkula is highly contaminated and proper treatment techniques must be ensured before discharging the leachate.

Table 3.4.1a: LPI of the leachate from Chandigarh dumping site

Parameters	Concentration			Weights (w_i)	Individual pollution rating (p_i)			Overall pollution rating ($w_i \times p_i$)		
	S1	**S2**	**S3**		**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
pH	9.6	9.1	9.0	0.055	25	20	20	1.375	1.1	1.1
TDS	3590	3669	3669	0.050	10	13	13	0.5	0.65	0.65
BOD	360	420	425	0.061	11	13	13	0.671	0.793	0.793
COD	19930	19950	19961	0.062	55	58	60	3.41	3.596	3.72
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1150	1200	1210	0.051	100	100	100	5.1	5.1	5.1
Total Fe	11.2	12.2	12.1	0.045	8	10	10	0.36	0.45	0.45
Cu	3.72	3.80	3.66	0.05	11	11	10	0.55	0.55	0.5
Ni	0.98	0.98	0.96	0.052	7	7	7	0.364	0.364	0.364
Zn	10.41	11.60	12.2	0.056	7	8	10	0.392	0.448	0.56
Pb	0.64	0.66	0.70	0.063	7	8	10	0.441	0.504	0.63

Cr	0.14	0.16	0.20	0.064	6	8	9	0.384	0.512	0.576
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	2136	2230	2320	0.048	20	22	25	0.96	1.056	1.2
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	8×10^7	8×10^7	10×10^7	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**19.707**	**15.123**	**20.843**
LPI								27.80	21.30	29.36
LPI (Mean of all the three samplings)									**26.15**	

Table 3.4.1b: LPI of the leachate from Mohali dumping site

Parameters	Concentration			Weights (w_i)	Individual pollution rating (p_i)			Overall pollution rating ($w_i \times p_i$)		
	S1	**S2**	**S3**		**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
pH	8.9	9.0	9.0	0.055	10	20	20	0.55	1.1	1.1
TDS	3161	3280	3290	0.050	13	15	15	0.65	0.75	0.75
BOD	470	490	510	0.061	15	15	18	0.915	0.915	1.098
COD	17323	17940	17968	0.062	50	52	55	3.1	3.224	3.41
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1190	1239	1328	0.051	100	100	100	5.1	5.1	5.1
Total Fe	7.72	7.80	7.85	0.045	5	6	6	0.225	0.27	0.27

Cu	3.32	4.90	4.85	0.05	8	11	11	0.4	0.55	0.55
Ni	0.77	0.99	0.99	0.052	5	7	7	0.26	0.364	0.364
Zn	8.4	8.6	8.7	0.056	5	5	5	0.28	0.28	0.28
Pb	0.07	0.07	0.08	0.063	5	5	5	0.315	0.315	0.315
Cr	2.47	3.20	3.20	0.064	5	6	6	0.32	0.384	0.384
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	1659	1780	1786	0.048	20	20	20	0.96	0.96	0.96
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	7×10^7	8×10^7	7×10^6	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**18.275**	**19.412**	**19.781**
LPI								25.78	27.38	27.90
LPI (Mean of all the three samplings)									**27.02**	

Table 3.4.1c: LPI of the leachate from Panchkula dumping site

Parameters	Concentration			Weights (w_i)	Individual pollution rating (p_i)			Overall pollution rating ($w_i \times p_i$)		
	S1	**S2**	**S3**		**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
pH	8.6	9.1	9.0	0.055	5	20	20	0.275	1.1	1.1
TDS	3048	3100	3100	0.050	11	9	9	0.55	0.45	0.45
BOD	310	360	370	0.061	8	11	11	0.488	0.671	0.671

COD	18208	19910	19920	0.062	50	58	58	3.1	3.596	3.596
TKN	-	-	-	-	-	-	-	-	-	-
NH_3-N	1010	1022	1030	0.051	100	100	100	5.1	5.1	5.1
Total Fe	8.83	8.89	8.88	0.045	9	13	13	0.405	0.585	0.585
Cu	2.23	2.40	2.40	0.05	8	9	9	0.4	0.45	0.45
Ni	0.87	0.87	0.88	0.052	7	7	7	0.364	0.364	0.364
Zn	8.39	8.41	8.60	0.056	5	6	7	0.28	0.336	0.392
Pb	0.11	0.19	0.20	0.063	6	9	9	0.378	0.567	0.567
Cr	0.75	0.89	0.90	0.064	9	11	11	0.576	0.704	0.704
Hg	-	-	-	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-
Cl^-	2011.5	2100	2122	0.048	25	28	28	1.2	1.344	1.344
Cyanide	-	-	-	-	-	-	-	-	-	-
Total Coliforms	9×10^6	9×10^7	9×10^6	0.052	100	100	100	5.2	5.2	5.2
Total				**0.709**				**18.316**	**20.467**	**20.523**
LPI								25.83	28.87	28.95
LPI (Mean of all the three samplings)									**27.88**	

3.4.2 WQI

The sub-indices values of ground water from Chandigarh, Mohali and Panchkula are given in Table 3.4.2a, 3.4.2b and 3.4.2c respectively. The variations in all the parameters have shown that with the decrease in sub-index value the related possible contamination levels in ground water increases. In the present study WQI is calculated using OWQI method and values for

all the three cities of Chandigarh, Mohali and Panchkula respectively. The values of WQI obtained were Chandigarh 83.8, 73.5 and 72.4, Mohali 54.3, 58.3 and 66.1, Panchkula 80.8, 77 and 71.4 during first, second and third sampling respectively. The outcome of quality of ground water for Chandigarh lies from "fair quality of water" to "poor quality of water", for Mohali and Panchkula; it is ranged as "very poor quality" to "poor quality of ground water". The results clearly suggest that the quality of water observed in all the three cities may cause severe health related to the population.

Table 3.4.2a: Observation of WQI for Chandigarh

Parameters	**X- distance (Km)**	**Chandigarh**					
		S1		**S2**		**S3**	
		q	**s**	**q**	**s**	**q**	**s**
pH	1	7.8	0.522	9.1	0.207	9.1	0.207
	2	7.6	0.610	8.2	0.387	8.3	0.359
	2.5	7.3	0.775	8	0.448	8	0.448
	3	7.1	0.918	7.9	0.484	7.96	0.462
	4	7.2	0.844	7.4	0.716	7.7	0.564
	5	6.8	1.189	7.2	0.844	7.1	0.918
TSS	1	643.2	0.269	680.1	0.253	687	0.251
	2	1191	0.139	1200	0.137	1200	0.137
	2.5	677.7	0.254	770.2	0.222	787	0.217
	3	597.7	0.290	600.9	0.289	632.1	0.274
	4	492.6	0.355	510	0.343	517	0.338
	5	482.6	0.363	550	0.317	555	0.314
Ammonical Nitrogen (NH_3-N)	1	1.36	0.904	1.4	0.901	1.41	0.901
	2	0.96	0.931	0.98	0.929	0.99	0.929
	2.5	0.38	0.972	0.39	0.971	0.39	0.971
	3	0.21	0.984	0.3	0.977	0.31	0.977
	4	0.2	0.985	0.22	0.983	0.27	0.980
	5	0.1	1	0.19	0.985	0.2	0.985
Turbidity	1	10	0.760	10	0.760	9	0.780
	2	7	0.821	7	0.821	7	0.821
	2.5	6	0.843	7	0.821	8	0.800
	3	4	0.890	6	0.843	6	0.843
	4	2	0.942	4	0.890	5	0.866
	5	2	0.942	2	0.942	3	0.916

Table 3.4.2b: Observation of WQI for Mohali

Parameters	X- distance (Km)	Mohali					
		S1		S2		S3	
		q	s	q	s	q	s
pH	1	8.8	0.253	8.9	0.236	9.2	0.194
	2	8.4	0.334	8.3	0.359	8.3	0.359
	2.5	8	0.448	7.9	0.452	7.9	0.480
	3	7.9	0.484	7.7	0.564	7.2	0.844
	4	7.9	0.484	7.6	0.610	7	1
	5	7.6	0.610	6.6	1.422	6	2.522
TSS	1	783.3	0.2183	788.1	0.216	789	0.216
	2	626.7	0.276	642	0.269	650	0.266
	2.5	597.7	0.2910	599	0.290	599	0.290
	3	550	0.317	562.7	0.310	568.1	0.307
	4	494	0.354	500	0.350	500	0.350
	5	492	0.355	521.9	0.335	530.1	0.330
Ammonical Nitrogen (NH_3-N)	1	0.77	0.944	0.96	0.931	1.22	0.913
	2	0.13	0.990	0.27	0.980	0.9	0.935
	2.5	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
Turbidity	1	9	0.780	10	0.760	10	0.760
	2	9	0.780	9	0.780	9	0.780
	2.5	8	0.800	9	0.780	10	0.760
	3	8	0.800	8	0.800	8	0.800
	4	7	0.821	8	0.800	8	0.800
	5	6	0.843	7	0.821	7	0.821

Table 3.4.2c: Observation of WQI for Panchkula

Parameters	X- distance (Km)	Panchkula					
		S1		S2		S3	
		q	s	q	s	q	s
pH	1	7.8	0.522	7.8	0.514	8.1	0.416
	2	7.6	0.610	7.6	0.610	7.7	0.564
	2.5	7.5	0.660	7.5	0.660	7.5	0.660
	3	7	1	7.2	0.844	7.3	0.777
	4	6.6	1.422	6.6	1.422	6.7	1.300
	5	6	2.522	6	2.522	6	2.522
TSS	1	582.4	0.299	590	0.295	592.1	0.294
	2	577.6	0.301	531.2	0.329	530	0.330
	2.5	550	0.317	500	0.350	500	0.350
	3	491	0.357	489.2	0.358	460	0.381
	4	376	0.465	299.7	0.572	299	0.573
	5	330	0.525	249.6	0.662	236.1	0.690
Ammonical Nitrogen (NH_3-N)	1	1.68	0.88	0	0	0	0
	2	0.78	0.943	0.79	0.943	0.8	0.942
	2.5	0.15	0.988	0.15	0.988	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
Turbidity	1	10	0.760	10	0.760	10	0.760
	2	10	0.760	10	0.760	10	0.760
	2.5	9	0.780	9	0.780	9	0.780
	3	7	0.821	7	0.821	7	0.821
	4	7	0.821	8	0.800	8	0.800
	5	4	0.890	4	0.890	3	0.916

3.4.3 Multivariate Analysis

3.5.3.1 Principal components analysis (PCA)

Three principal components were obtained with Eigen values greater than unity in case of Chandigarh and Panchkula cities accounting for almost 88% and 87.8% of total variance respectively in the ground water dataset whereas for Mohali, two components with Eigen values greater than unity accounting 87.1% of total variance in the ground water dataset.

Figure 3.4.3.1a, 3.4.3.1b and 3.4.3.1c shows the plot of loadings for various components of Chandigarh, Mohali and Panchkula respectively.

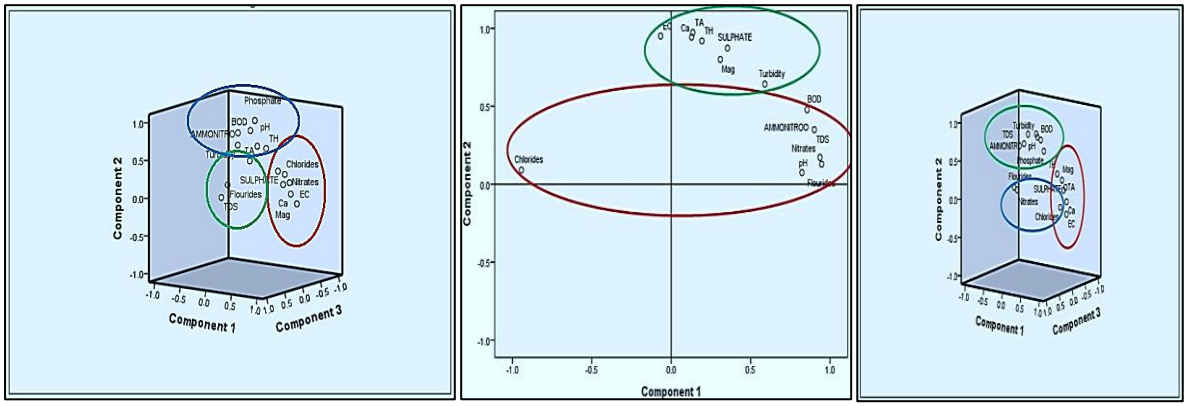


Figure 3.4.3.1a, 3.4.3.1b and 3.4.3.1c: Loadings for the components with varimax normalized rotation for Chandigarh, Mohali and Panchkula respectively

Component 1 The first component in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulphate and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. The moderate positive loading is shown in pH, turbidity and total hardness accounting for 62.755%, 62.140% and 51.966% of the total variance in first components of Chandigarh, Mohali and Panchkula cities respectively.

Component 2

The second component is dominated by the presence of sulphate, ammonical nitrogen, turbidity, biochemical oxygen demand, total hardness, pH, electrical conductivity and magnesium, accounting for 17.937%, 24.984% and 22.874% of the total variance for Chandigarh, Mohali and Panchkula respectively. The high loading in pH is related to the low sulphate ions as pH is negatively correlated with the sulphate.

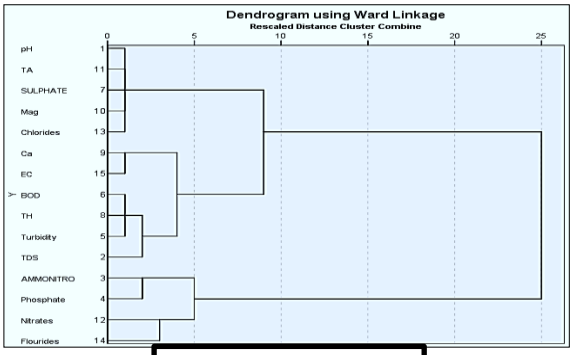
Component 3

Component three explaining 7.309% and 1.956% of total variance for Chandigarh and Panchkula respectively has strong positive loading on phosphate and fluoride. Generally, alkaline environment is responsible for the presence of fluoride in ground water.

3.4.3.2 *Hierarchical cluster analysis (HCA)*

The classification of ground water samples into clusters is based on a visual observation of the dendogram and is represented in Figures 3.4.3.2a, 3.4.3.2b and 3.4.3.2c for Chandigarh,

Mohali and Panchkula respectively. In this study, for all the three cities the classification of all the 45 ground water samples (15 samples for each of the three cities) into clusters is formed. The three different clusters for Chandigarh, Mohali and Panchkula cities are formed: **cluster 1** (sampling sites 1, 11, 7, 10, 13 for Chandigarh; sampling sites 27, 29, 18-19 for Mohali; sampling sites 42, 44, 33-34 for Panchkula), **cluster 2** (sampling sites 9, 15, 6, 8, 5,2 for Chandigarh; sampling sites 26, 30, 25, 20, 22, 16-17 for Mohali; sampling sites 40, 45, 41, 31 for Panchkula) and **cluster 3** (sampling sites 3-4, 12, 14 for Chandigarh; sampling sites 23-24, 21, 28 for Mohali; sampling sites 32, 35-36, 43 for Panchkula). These all respective sites for all the three cities of Chandigarh, Mohali and Panchkula respectively have similar characteristic features which corresponds to low, medium and high pollution region.



Figures 3.4.3.2a

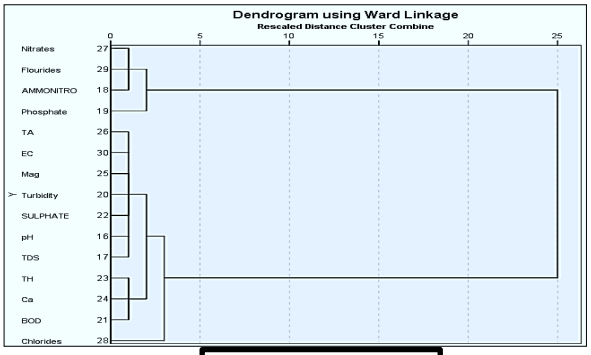


Figure 3.4.3.2b

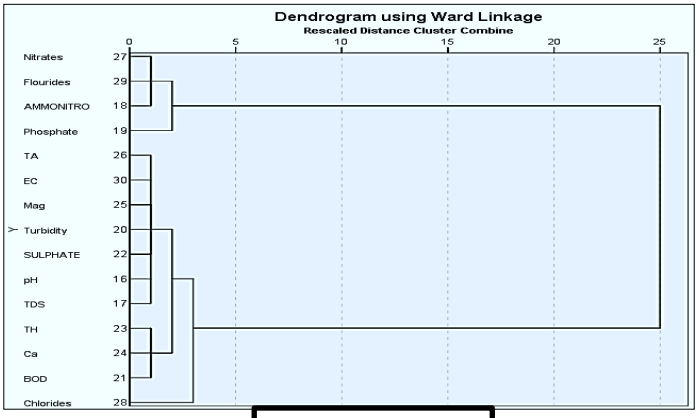


Figure 3.4.3.2c

Figures 3.4.3.2a, 3.4.3.2b and 3.4.3.2c: Hierarchical dendogram for ground water samples in Chandigarh, Mohali and Panchkula respectively

In cluster 1, five samples for Chandigarh City and four samples each for Mohali and Panchkula cities respectively are grouped and characterized by low polluted regions. In Chandigarh city, these samples are characterized by low pH, sulphate, magnesium and chloride whereas for Mohali and Panchkula the low values of these samples are characterized in nitrates, ammonical nitrogen, fluorides and phosphates. The ground water which falls under cluster 1 is not much polluted.

In cluster 2, six samples from Chandigarh, seven samples from Mohali and four samples from Panchkula are grouped characterized by moderate polluted region. Members of this cluster have presence of calcium, magnesium, electrical conductivity, biochemical oxygen demand, alkalinity and turbidity. The water samples shows moderate salinity with presence of total dissolved solids. This water can be classified as mixed water type (Singh et al. 2016).

In cluster 3, four samples each from Chandigarh and Mohali, and seven samples from Panchkula are grouped and characterized by the sites which are closer to the landfill sites and are found to be highly polluted owing to impact from domestic waste. The samples are characterized by presence of high ammonical nitrogen, nitrates, sulphate, hardness, fluorides and total dissolved solids.

3.5 Environmental Impacts of Scenarios of LCA

3.5.1 MSW Management Scenarios

Figures 3.5(a-l) shows the environmental impacts in the form of global warming, eutrophication, acidification and human toxicity under different waste management scenarios. Among the proposed alternative scenarios, the scenario with the combination of recycling, composting and sanitary landfill has least environmental impacts. The results show that the significant environmental savings are achieved through the energy recovery in all the integrated waste management scenarios. It is clear that there is no single MSW management scenario that performs best in all the impact categories.

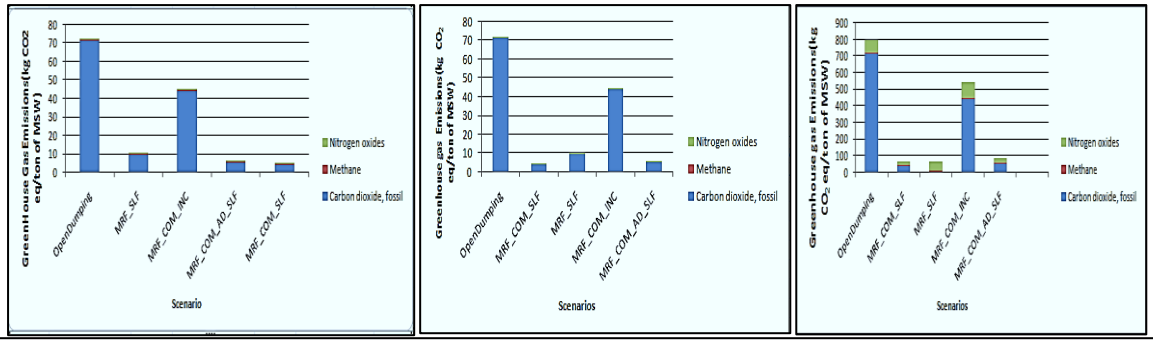


Figure 3.5a, b and c: Global Warming under different waste scenario in Chandigarh, Mohali and Panchkula respectively

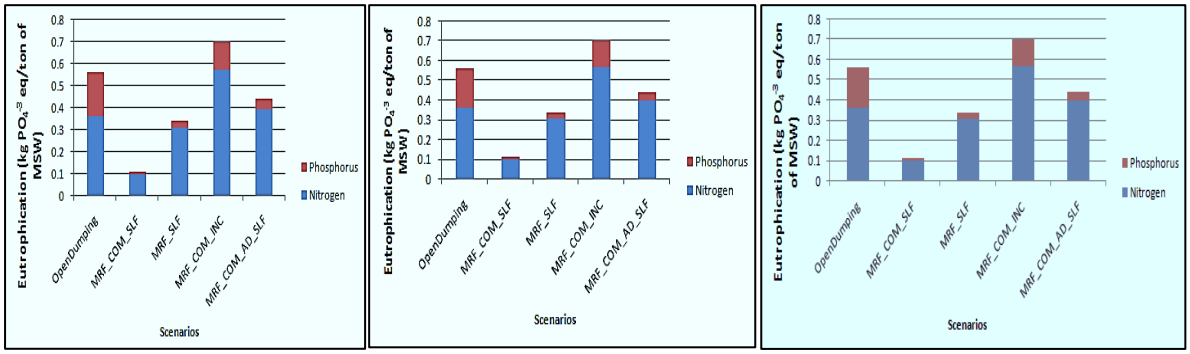


Figure 3.5d, e and f: Eutrophication under different waste scenario in Chandigarh, Mohali and Panchkula respectively

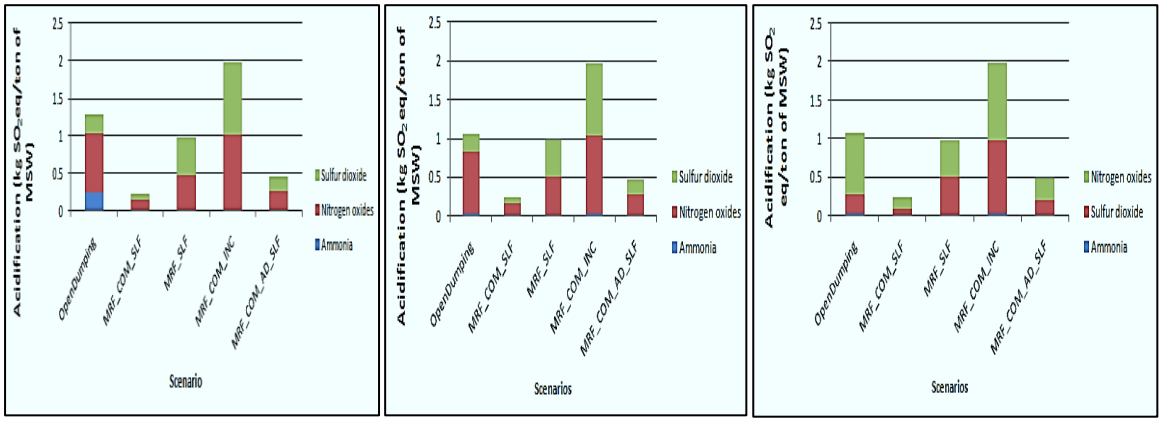


Figure 3.5 g, h and i: Acidification under different waste scenario in Chandigarh, Mohali and Panchkula respectively.

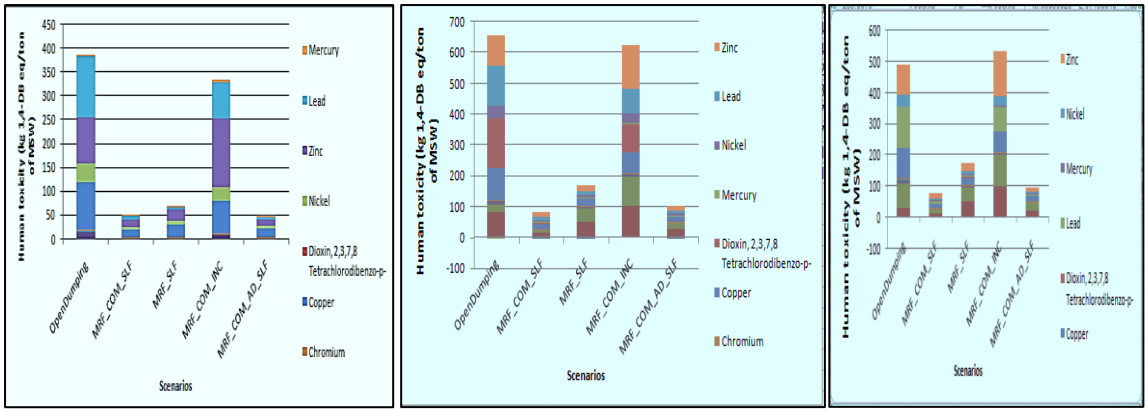


Figure 3.5j, k and l: Human Toxicity Potential under different waste scenario in Chandigarh, Mohali and Panchkula

3.5.2 Sensitivity Analysis to recycling rate

The recycling rate considerably lowers the impact of life cycle emissions. The effect of recycling rate on different impact categories was observed on 10% and 90% recycling rate. The result of the impact categories is presented in Table 3.5.2.

	GWP (CO_2 eq)	AP (SO_2 eq)	EP (PO_4^{-3}eq)	HTP (1,4-DB eq)
CHD	**[a]72.63 kg CO_2 eq t^{-1}** TO **[b]70.79 kg CO_2 eq t^{-1}**	**[a] 1.26 kg SO_2 eq t^{-1}** TO **[b] 0.94 kg SO_2 eq t^{-1}**	**[a] 0.35 kg PO_4^{-3} eq t^{-1}** TO **[b] 0.20 kg PO4 $^{-3}$ eq t^{-1}**	**[a] 1.30 kg 1,4-DB eq t^{-1}** TO **[b] 1.13 kg 1,4-DB eq t^{-1}**
MOH	**[a] 71.63 kg CO_2 eq t^{-1}** TO **[b] 69.07 kg CO_2 eq t^{-1}**	**[a] 0.92 kg SO_2 eq t^{-1}** TO **[b] 0.82 kg SO_2 eq t^{-1}**	**[a] 0.82 kg PO_4^{-3}** TO **[b] 0.20 kg PO4 $^{-3}$ eq t^{-1}**	**[a] 1.30 kg 1,4-DB eq t^{-1}** TO **[b] 1.19 kg 1,4-DB eq t^{-1}**
PKL	**[a] 716.3 kg CO_2 eq t^{-1}** TO **[b] 680.53 kg CO_2 eq t^{-1}**	**[a] 1.02 kg SO_2 eq t^{-1} TO [b] 0.79 kg SO_2 eq t^{-1}**	**[a] 0.35 kg PO_4^{-3} eq t^{-1} TO [b] 0.20 kg PO4 $^{-3}$ eq t^{-1}**	**[a] 99.60 kg 1,4-DB eq t^{-1} TO [b] 79.45 kg 1,4-DB eq t^{-1}**

[[a]10%; [b]90%]

4. CONCLUSIONS

4.1 General

This chapter comprises the summary of observations and conclusions derived from the field and laboratory investigations performed to meet the objective of the study.

4.2 Conclusions

The salient observations of the study are:

- Existing practices of waste management practice in Tricity indicates that practice of door-to-door collection system, presence of waste transfer stations, waste treatment plant (RDF), regular monitoring agency, public-private participation and effective street sweeping 'manually and mechanized' makes this city one step ahead as compared to other cities. However, some shortcomings have been observed in the existing management system which needs immediate attention. It was observed that management of waste becomes difficult during monsoons due to higher moisture content. No treatment of organic fraction of waste is practiced; it is dumped in the open dumping sites, thereby contributing to environmental pollution. Further, no active sanitary landfill site is present in the city for disposal of waste and entire stream of waste ends up in dumping site which is non-engineered landfill.
- Prediction of MSW generation plays a vital role in MSW management. Based on the MSW characterization from Chandigarh, Mohali and Panchkula, it is suggested that a single existent technology like RDF cannot lead to complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste
- Leachate produced from dumping site is released directly into the environment. Presence of COD in water samples confirms the percolation of organic contaminants to the groundwater and makes it unsuitable for drinking purposes. The concentrations of heavy metals such as Pb and Cu were found to be above the permissible limit prescribed by BIS (2012). Furthermore, the presence of TCB in some of the samples confirms that the infiltration of leachate into the groundwater has deteriorated the quality. The quantitative analysis for PAHs in the leachate samples showed benzo (a) pyrene-toxic equivalence quotient (BaP-TEQ) ranging from 32.4972 $\times 10^{-2}$ to 78.2571$\times 10^{-2}$ mg/lt. The methodology used for assessing the human risk assessment

involved evaluation of the hostile effects of PAHs and has shown that the cancer risk (CR) was lower than the acceptable risk of 10^{-6}. Methyl tetrazolium (MTT) assay for cytotoxicity was carried out in Neuro-2a cell lines to further evaluate the potential toxicity of the leachate samples. The MTT EC_{50} (Effective Concentrations) values ranged from 9.99 to 15.46% affirming the significant cytotoxic effect of leachates on Neuro-2a cell line.

- LPI is an essential tool which enables to compare the pollution potential of landfill sites. In the present study LPI values of 26.15, 27.02 and 27.88 were obtained for Chandigarh, Mohali and Panchkula respectively signifying the immediate attention towards the dump sites to avoid any big pollution incident. High values of LPI obtained in all the landfill sites indicated that the leachate generated is contaminated and proper treatment procedures must be ensured. The ground water quality of nearby sites of municipal solid waste landfill sites are of poor quality since they are contaminated due to leachate. The WQI of ground water samples from all the three cities of Chandigarh, Mohali and Panchkula were performed. The WQI for three sampling period varied in the range of 83.8, 73.5 and 72.4 for Chandigarh, 54.3, 58.3 and 66.1 for Mohali and 80.8, 77 and 71.4 for Panchkula. As per OWQI, the ground water for Chandigarh is categorized as "fair quality to poor quality and for Mohali and Panchkula it is categorized as "very poor quality to "poor quality" of ground water. Multivariate statistical technique (PCA and HCA) suggests that the components of the PCA accounts for 88%, 87.1% and 87.7% of the total variance in the dataset for Chandigarh, Mohali and Panchkula cities respectively. The components in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulphate and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. Cluster analysis helped to group 15 sampling sites each for Chandigarh, Mohali and Panchkula into three clusters of similar characteristics. It further helps to examine the quality of water and sources of pollution. In the future, it is recommended to have an engineered landfill sites for each of the three cities which can control the impact of leachate on the ground water.

- The LCA was accomplished using the simapro software version 8.3.0 and expressed with the Eco-Indicator 99 (H) and Eco-Invent method. The sensitivity analysis identifies sensitive parameters, that is, whether a small change in input parameter would induce a

large change in impact category. The input parameters for sensitivity analysis focus on the recycling rate. Overall, MSW management scenarios with the combination of recycling, composting and sanitary landfill have least environmental impacts. It is clear that there is no single MSW management scenario that performs best in all the impact categories.

4.3 Recommendations

- Recruitment and training of additional sanitary workers should be carried out to increase collection efficiency. Segregation of waste should be carried out for the collected wastes generated from Tricity along with set up of formal recycling unit for Tricity.
- New sites must be considered for construction of these engineered landfill sites as the present dumpsites are nearing the end of their lifespan capacity.
- Based on the MSW characterization from Tricity, it is suggested that a single existent technology like RDF cannot lead to complete management of waste, but there is a need to adopt integrated technologies for the treatment of different fractions of waste, and hence for these cities a combination of composting, vermi-composting and bio-methanation plant, would help in achieving a better management system.
- Leachate collected near the dumping site could be extracted and treated so as to prevent its percolation into the groundwater.
- Regular monitoring of water should be done to study the long term effect of dumping site on groundwater quality.

4.4 Scope for Future Work

- An attempt can be made to evaluate the impact of MSW leachate on the properties of soil at the dumping sites of Tricity.
- A study can be undertaken to design an engineered sanitary landfill for Tricity having leachate collection and treatment facilities along with air pollution monitoring.
- A cost effective approach for dumping site rehabilitation can be performed.
- In order to have a holistic view of MSW management economic evaluation of the costs and benefits of the MSW proposed scenarios can be performed.

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6. LIST OF PUBLICATIONS

Journal Publications

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[2] Rana, Rishi., Ganguly, Rajiv., and Gupta, A.K. (2017). "Evaluation of Solid Waste Management in Satellite Towns of Mohali and Panchkula- India. *The Journal of Solid Waste Technology and Management.* [**Scopus Indexed, Accepted for publication in Volume 43, November 2017**]

[3] Rana, Rishi., Ganguly, Rajiv., and Gupta, A.K. (2017). "Physico-Chemical Characterization of Municipal Solid Waste from Tri-city region of Northern India - A case study. *The Journal of Material Cycles and Waste Management,* DOI 10.1007/s10163-017-0615-3. [**Springer, SCI Indexed, Impact Factor (2016/2017) – 1.604**]

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Conference Publications

[1] Rishi Rana, Rajiv Ganguly, Ashok Kumar Gupta (2014). Solid Waste Management in Chandigarh: a case study. *Journal of Civil Engineering and Environmental Technology, 1* (4), 67-70. Google Citation

[2] Rishi Rana, Rajiv Ganguly, Ashok Kumar Gupta (2016). Impact of Leachate from non-engineered landfill sites on groundwater quality: a case study in Northern India. *Proceedings of the International Conference on Trends and Recent Advances in Civil Engineering (TRACE)* [Amity University, Noida, India: August 11-12, 2016], pp.11-14. Google Citation.